ARTICLES

USE OF AERIAL COLOR INFRARED PHOTOGRAPHY AS A SURVEY TECHNIQUE FOR *PSOROPHORA COLUMBIAE* OVIPOSITION HABITATS IN TEXAS RICELANDS[1]

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ABSTRACT. This study investigated the possibility of using aerial color infrared (CIR) photography as a survey technique for egg populations of *Psorophora columbiae* within a riceland agroecosystem. To accomplish this, eight photographic missions were flown over study fields during a variety of seasons and at various altitudes. Assessment of resulting photographic data indicates features reported in the literature as being attractive for oviposition by *Ps. columbiae* (i.e., rice field levees, tire tracks, ditches and low areas) can be readily detected on aerial CIR photographs. Features associated with *Ps. columbiae* oviposition sites were easily visible on photographs at scales as small as 1:42,000.

INTRODUCTION

Knowledge of the distribution and activity of *Psorophora columbiae* (Dyar and Knab), a major pest of man and livestock which has been implicated as a vector in the transmission of several important disease agents (Bishop 1933, Sudia and Newhouse 1971, Olson and Grimes 1974), is basic to developing and implementing effective management strategies that will reduce the importance of this species in such habitats as are found in the rice-producing areas of the southern United States. Crop rotation and flooding and draining of fields in riceland agroecosystems make ground survey techniques currently employed by mosquito control agencies time-consuming, expensive and possibly equivocal. Mosquito control agencies need less expensive, more efficient methods of locating and assessing breeding habitats for populations of *Ps. columbiae*. Use of aerial color infrared photography (CIR) may provide a solution to this problem.

Remote sensing techniques are generally considered to be quicker, less expensive and more accurate than ground survey techniques (Colwell 1963). Aerial CIR photography has been used to locate mosquito breeding habitats in the marshland ecosystem (Arp 1975, Barnes and Cibula 1979), but no attempt has been made to use this remote sensing technique in riceland agroecosystems.

A variety of features present in the riceland agroecosystem are attractive to *Ps. columbiae* mosquitoes for oviposition. Schwardt (1939) reported riceland supply canals, ditches, seepage areas and natural depressions in the soil are attractive sites for *Ps. columbiae* oviposition. Rice fields and areas where periodic shallow ground pools form are also known to be attractive to this species (Horsfall 1955). Later studies showed that rice field and pasture levee slopes, as well as cattle hoofprints and farm vehicle tire tracks, are particularly attractive to *Ps. columbiae* females as sites for oviposition (Meek and Olson 1976, 1977). The potential importance of certain features in fields planted to soybeans as sources of oviposition habitats in southern riceland systems has been demonstrated by Welch et al. (1986), with the concentration of eggs in low areas of soybean fields (Welch and Olson 1987).

In regard to using remote sensing techniques for the detection of potential *Ps. columbiae* oviposition habitats occurring in riceland habitats, several different techniques have already been assessed as to their efficacy for such a use in other types of mosquito-breeding habitats. For example, multiband aerial photography has been used to locate breeding habitats of *Aedes sollicitans* (Walker) in coastal marshlands (NASA 1973, Arp 1975), thus allowing techniques used for the automated classification of marshland vegetation to facilitate control of mosquito breeding (Cibula 1976). Woodzick and Maxwell (1977) reported that multidate classification of ground cover can be used to delineate mosquito breeding potential. Fleetwood et al. (1981) found that aerial visual surveillance plus ground in-

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spection of agricultural practices as they relate to *Ps. columbiae* production was an improvement over conventional ground surveillance. Aerial CIR photography was used as a rapid and accurate method of data acquisition for a new mosquito control district in Michigan (Wagner et al. 1979). Satellite imagery has been used to define temperature, altitude and vegetative cover to support studies of mosquitoes and other insects (Barnes and Cibula 1979). Recently, satellite imagery has also been used to identify and classify mosquito larval habitats associated with freshwater plant communities, wetlands and other aquatic locations (Hayes et al. 1985).

Since research has already shown that agricultural practices in themselves strongly influence where in and the degree to which *Ps. columbiae* will use different types of fields in a riceland agroecosystem (Meek and Olson 1976, 1977; Welch and Olson 1987, Welch et al. 1986), remotely sensed data updating changes in riceland agricultural practices would, thus, be very useful to mosquito control practitioners. In this regard, aerial photography has proven to be a very useful technique in providing such information about agricultural practices. For example, Goodman (1959, 1964) used black and white aerial photography to differentiate between crops and farming practices. Anson (1966) compared black and white, color and CIR films for assessing vegetative types and land use in agricultural areas. Anson concluded that CIR was superior to the other films for the extraction of vegetative detail and mapping of cultivated and fallow cropland. Aerial CIR photography has also been used to assess flood damage to agriculture (Anderson 1977).

Knowledge of soil moisture distribution in the riceland agroecosystem is also valuable in determining potential oviposition sites for *Ps. columbiae* in southern riceland agroecosystems (Olson and Meek 1977, 1980; Rankin and Olson 1985). Several examples of using remote sensing techniques for the survey of soil moisture content have been presented in the literature. Techniques include color (Cooper and Smith 1966, Werner et al. 1971, Kearney 1977) and CIR photography (Sewell and Allen 1973, Anderson 1977, Blazquez et al. 1981), passive microwave (Newton et al. 1974, Schanda et al. 1978, Jackson et al. 1981), active microwave (Idso et al. 1975a, Kearney 1977), thermal inertia (Idso et al. 1975b, Pratt and Ellyett 1978) and thermal infrared (Myers et al. 1966, Idso et al. 1975a).

Our interpretation of the literature suggests that determinations of soil moisture content with considerable accuracy is possible using color and CIR photography. Werner et al. (1971) concluded that the red band of reflected radiation gave the best results for soil moisture determination in their investigation. Kearney (1977) studied soil moisture levels in fallow fields and fields with crops and concluded that color and CIR photographs are suitable to tell whether the soil surface is moist. Allen[5] and Blazquez et al. (1981) reported that moisture patterns were easily seen on CIR photography and that dry areas appeared light and wet areas appeared dark.

Thus, the capability to differentiate moist soil from dry soil (Allen,[5] Blazquez et al. (1981), availability, cost and relative ease of interpretation (compared to other remote sensing techniques) imply aerial CIR photography may be a useful technique to survey potential mosquito production sites in southern riceland agroecosystems. Previous use of aerial color photography as a surveillance technique for insect activity, agricultural land-use and soil moisture patterns has proved efficacious. These properties of aerial CIR photography suggest that this method may be the remote sensing technique of choice for mosquito control practitioners to survey mosquito habitats. Our study investigated the possibility of using aerial CIR photography as a survey technique for potential oviposition sites of *Ps. columbiae* within southern riceland agroecosystems. Objectives of this study were: 1) to differentiate and survey the field components of the riceland agroecosystems with aerial CIR photography using characters (patterns or features on photographs) developed for this study, and 2) to identify potential *Ps. columbiae* oviposition habitats within the different field components using photographic signatures developed during this study.

METHODS

Location of study sites: Pastures, rice and soybean fields used within the study were in Chambers County, Texas (see Welch et al. 1986). Fields were located west of the Old River in a Beaumont-Morey-Lake Charles soil association (Crout 1976). This soil association has been characterized as level or nearly level, acid to neutral, clayey and loamy soils with very slow permeability, which allows water to stand for long periods after heavy rainfall. Additional study fields were located ca. 24.8 km southeast of the other fields in a Vaiden-Acadia-Calhoun soil association characterized as being nearly level with slightly depressed areas where water stands for long periods after heavy rains (Crout 1976).

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[5] Allen, W. H. 1972. Remote sensing of fallow soil moisture using visible and infrared sensors. Ph.D. dissertation, Univ. of Tenn., Knoxville, 96 pp.

Table 1. Dates and specifications of photographic missions flown over riceland mosquito study sites in Chambers County, TX, from October 1979 to September 1981.

Date	Season	Camera	Focal length (in.)	Scale	Film type	Aircraft	Agency
Oct. 6, 1979	Fall	RC8	6	1/33,000	2443-2522	Cessna Tu-206	TAMU[a]
Oct. 11, 1979	Fall	Zeiss	6	1/42,000	SO-193	Lockheed NP3A Orion	NASA[b]
Mar. 21, 1980	Spring	RC8	6	1/15,000	2443	Cessna TU-206	TAMU
Jun. 10–11, 1980	Spring	KA2	12	1/4,000 1/6,000 1/8,000 1/10,000 1/12,000	2443	Aero Commander	USDA[c]
Aug. 21, 1980	Summer	K37	12	1/4,000 1/6,000 1/8,000 1/10,000	2443	Aero Commander	USDA
Oct. 3, 1980	Fall	RC8	6	1/8,000	2443	Cessna TU-206	TAMU
Jan. 23, 1981/Feb. 2, 1981	Winter	K37	12	1/6,500 1/9,500	2443	Aero Commander	USDA
Sept. 10, 1981	Summer	K37	12	1/6,500 1/10,000	2443	Aero Commander	USDA

[a] Texas A & M University, Remote Sensing Center, College Station, TX.
[b] National Aeronautics and Space Administration, Johnson Space Center, TX.
[c] United States Department of Agriculture/SEA/ARS, Weslaco, TX.

Collection and processing of soil samples: Soil samples were collected on a weekly basis from sites within study fields from June 1979 through April 1981 and again in June and September 1981. Soil samples of 15.24 × 15.24 × 2.54 cm were collected in a manner similar to that of Horsfall (1956) and described in detail by Welch et al. (1986). Soil moisture content was estimated using the hand-squeeze technique (Box and Bennett 1959) as adapted for mosquito studies by Olson and Meek (1977). Each sample was processed and examined for the presence of *Ps. columbiae* eggs as detailed in Welch.[6]

Acquisition of photography: Eight aerial CIR photographic missions were flown over the study sites during the period of investigation (Table 1). Three overflights were provided by the staff of A. R. Benton, Jr., Remote Sensing Center, Texas A&M University, College Station, Texas. One mission was obtained by courtesy of C. M. Barnes, National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Clear Lake City, Texas. The remainder of the photographic missions were provided by the staff of W. G. Hart, USDA-ARS, Weslaco, Texas. All photographic exposures were made in wavelengths from ca. 0.5–0.9 μm.

[6] Welch, J. B. 1983. The use of aerial color infrared photography as a survey technique for oviposition sites of *Psorophora columbiae* (Dyar and Knab) (Diptera: Culicidae) in a Texas riceland agroecosystem. Ph.D. dissertation, Texas A&M University, College Station, TX 227 pp.

Interpretation of photography: Interpretation of the aerial CIR photography resulting from each mission was conducted as soon as the photographs reached the Mosquito Research Laboratory at Texas A&M University (ca. 3–7 days after exposure). Photointerpretation of the resulting color transparencies was accomplished with the use of a portable light table and a dissecting stereomicroscope. During the course of interpretation, characters were developed to differentiate the field types comprising a riceland agroecosystem and potential *Ps. columbiae* oviposition habitats within each field type. Characters were developed by interpreting features based on the examination of the pictorial elements of size, shape, color, pattern, shadow, texture, and topographic location and association. Upon completion of the photointerpretation of the film from a given mission, ground verification was conducted within 7 days after receipt of the photographs. Ground verification consisted of taking the aerial CIR photographic prints to each study field to corroborate the pictorial elements with existing field conditions.

Munsell color chips (Munsell Color, MacBeth Division of Kollmorgen Corporation, Baltimore, MD) were used in the interpretation of color, but only as descriptors. Observations were made under standard conditions of illumination and viewing according to MacBeth Division of Kollmorgen Corporation (1966). Aerial CIR transparencies and Munsell color chips were viewed at a 90° angle with the light source falling upon them at an angle of 45°.

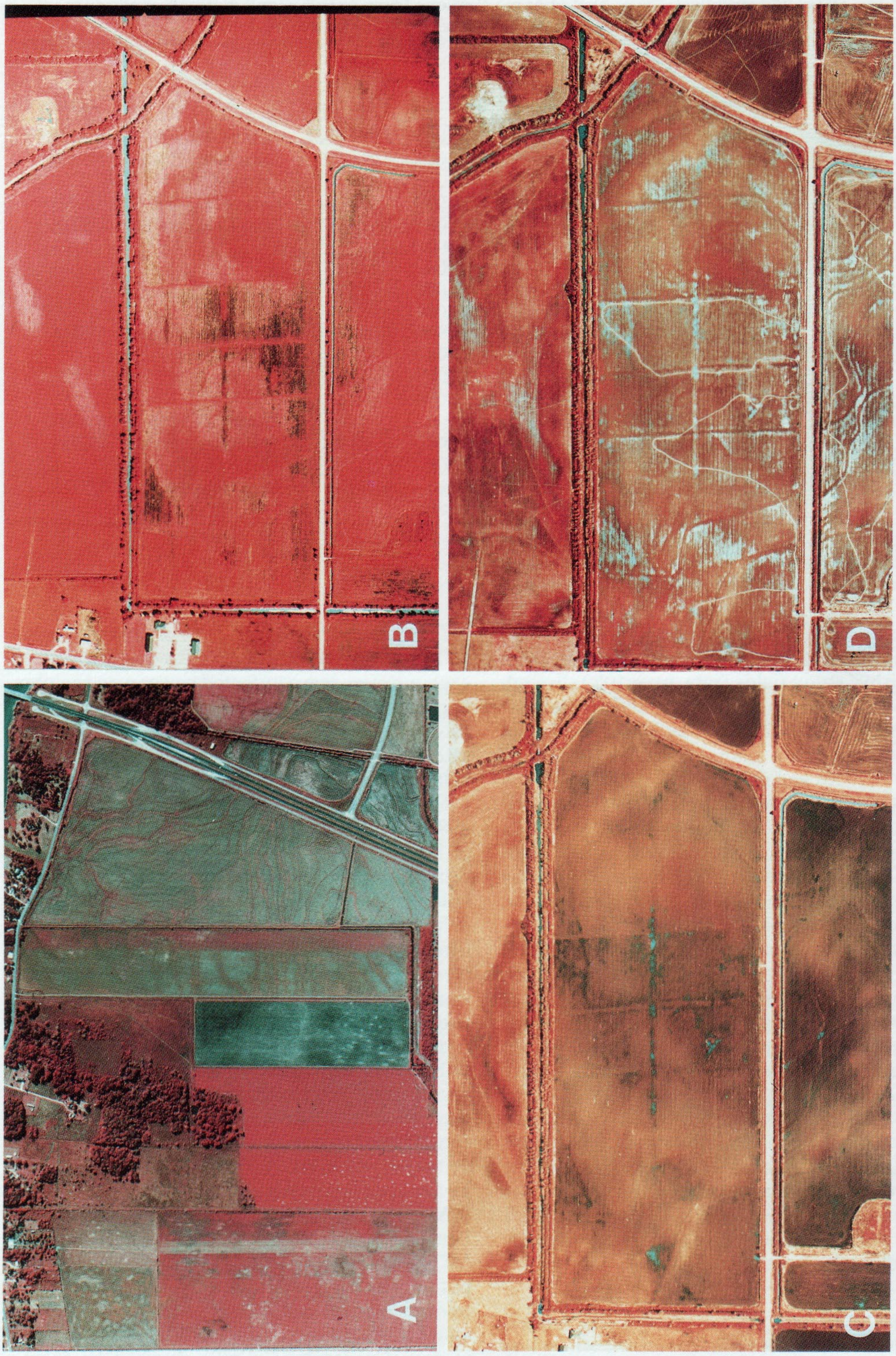

Fig 1. Aerial color in frared photographs showing: A) a typical agricultural area where rice is grown in Chambers County, TX, taken on October 6, 1979; B) study field 4-soybean taken on October 3, 1980; C) study field 4-soybean taken on January 23, 1981; and D) study field 4-soybean taken on February 2, 1981.

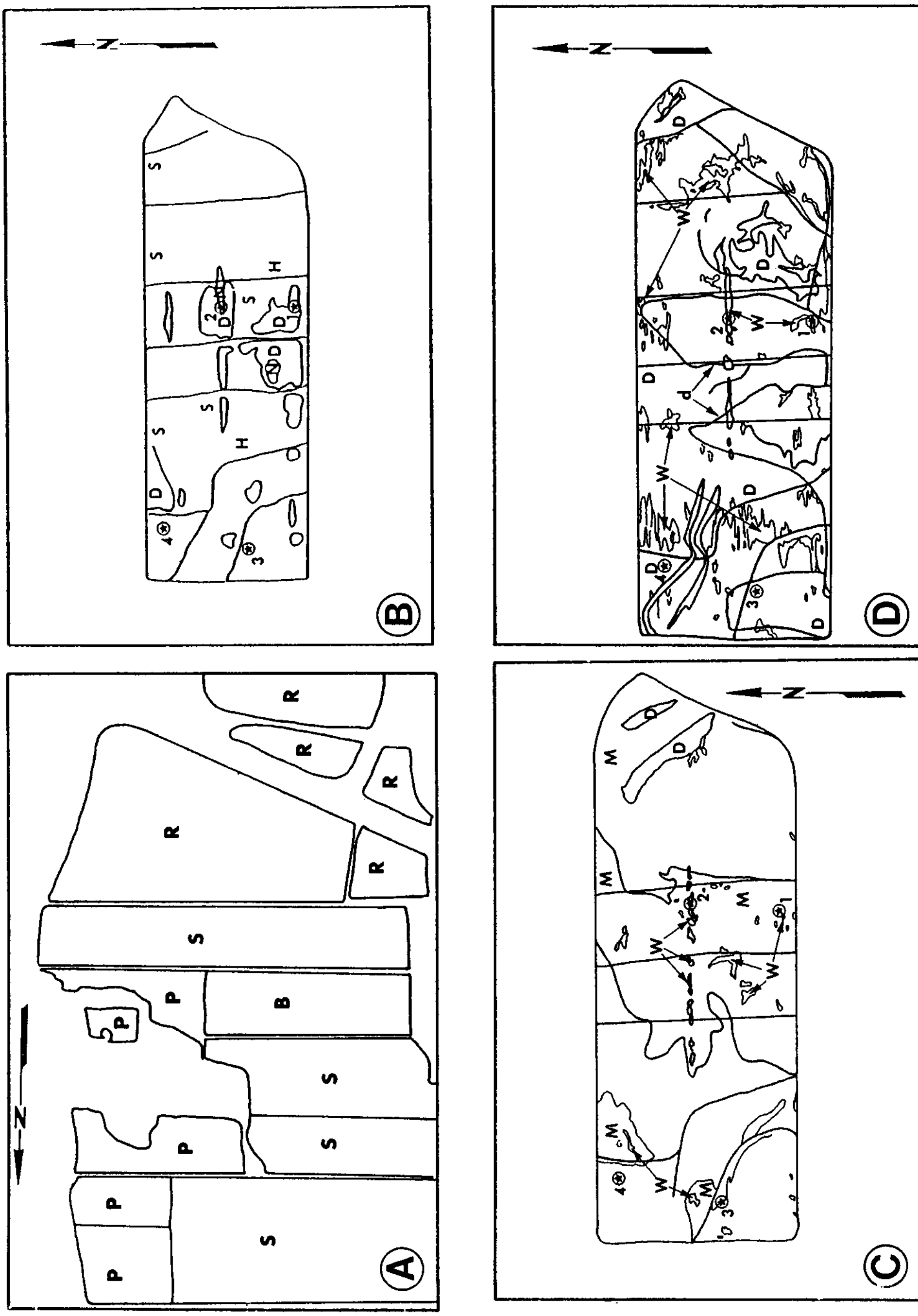

Fig. 2. Diagrams of photographs shown in Fig. 1 illustrating the following: A) the ability to locate and differentiate rice fields (R), soybean fields (S), permanent pastures (P) and bare soil in a cultivated field (B) as depicted in Fig. 1A; B) the appearance of sample areas 1–4 and areas of healthy (H), moisture stressed (S), dying and dead soybeans (D) and natural vegetation or weeds (N) as depicted in Fig. 1B; C) the appearance of sample areas 1–4 and higher, drier areas (D), lower, moist areas of soil (M) and low areas with standing water (W) as depicted in Fig. 1C; and D) the appearance of sample areas 1–4 and higher, drier areas (D), low areas with standing water (W) and water-filled ditches (d) as depicted in Fig. 1D.

RESULTS

Appearance of fields: Rice fields on aerial CIR photographs were generally variable in color, uniform to mottled in pattern, and smooth to rough in texture. The character found to be of primary importance in identifying fields planted to rice was the presence of levees, which appeared as distinct, raised, serpentine lines within fields (Figs. 1A and 2A). The coloration of rice fields on photographs was usually strong red to vivid red while the field was in crop, reddish-brown to moderate pink in areas of regrowth after harvesting, and light bluish-green to light greenish-blue in areas of no regrowth. The pattern and texture of rice crops were generally uniform and smooth, respectively. However, during and after harvest, rice fields appeared mottled in pattern and rough in texture with numerous farm vehicle tire tracks visible as parallel, double serpentine lines.

Fields planted to soybeans were also variable in color, uniform to mottled in pattern and smooth to rough in texture without distinct, raised, serpentine levees (Figs. 1A–D and 2A–D). Additionally, soybeans were planted in rows which may be visible on photographs. Healthy, well-drained fields of soybeans were characteristically uniform, smooth and vivid red to vivid reddish-orange. Fields planted to soybeans, however, were frequently mottled due to differences in plant vigor, often the result of excess soil moisture to which soybeans are intolerant. Areas of healthy plants are uniform, smooth and vivid red to vivid reddish-orange, whereas areas of stressed soybeans were generally mottled in pattern, smooth to rough in texture and pale pink to light pink to moderate pink in color. The appearance of areas of dying and dead soybeans was uniform, rough and moderate olive green on aerial CIR photographs.

Permanent pastures were highly variable in color, mottled in pattern and generally rough in texture on aerial CIR photographs (Figs. 1A and 2A). Due to the complex association of different plant communities present in permanent pastures of the region, these fields were always mottled in pattern, generally rough in texture and highly variable in color. Variations of purples, browns, greens, yellows, oranges, pinks and blacks, not seen in fields planted to rice or soybeans, were seen on CIR photographs of permanent pastures during this study.

Anson (1966) used aerial CIR photography to assess vegetative types and land-use, and reported that CIR was suitable for providing vegetative detail and mapping of cultivated cropland. During the present study, the use of aerial CIR photography was found to be excellent in the location and identification of fields within the riceland agroecosystem. Aerial CIR photographs were examined to locate possible fields for study and subsequent ground verification proved it to be 100% accurate in showing type of field (i.e., rice, soybean or permanent pasture). Baker et al. (1979) stated land-use/land-cover interpretation should be at least 90–95% accurate to prove functional.

Appearance of potential Ps. columbiae *oviposition habitats:* A summary of features on photographs of fields planted to rice or soybeans, and permanent pastures, indicating potential oviposition habitats (based on the literature and egg collections made during this study) of *Ps. columbiae* is presented in Table 2. Levees, areas of standing water (indicating localized depressions in fallow fields), dark areas of soil (indicating the presence of moisture), ditches and tire tracks appearing on photographs indicate potential oviposition habitats in rice fields. Potential oviposition habitats within fields planted to soybeans are indicated on photographs by areas of standing water, dark areas of soil, dark areas with few or no soybeans present during wet years, areas where soybeans are replaced by moisture tolerant weeds, fallow areas within soybean fields, ditches and tire tracks. Potential oviposition habitats within permanent pastures are indicated on aerial CIR photographs by the presence of areas of standing water, dark areas of soil, ditches, tire tracks and muddy paths of livestock.

A summary of the appearance on aerial CIR photographs of those features indicating potential *Ps. columbiae* oviposition habitats within fields is presented in the tables of this section. These appearances are discussed on a seasonal basis beginning with summer (Table 3).

Levees and farm vehicle tire tracks were variable in appearance of color and texture, but generally their pattern was consistent on aerial CIR photographs of rice fields during the summer. On photographs obtained during this study, levees ranged from moderate yellowish-pink to strong reddish-orange or strong red to dark reddish-orange, but were always serpentine in pattern and generally raised, rough in texture. Tire tracks in harvested fields appeared as parallel double, serpentine smooth lines which were pale yellow to dark yellow to yellowish-brown.

Low areas within fields planted to soybeans were identifiable by a variety of characters on aerial CIR photographs. Ditches appeared as smooth lines, pale orange yellow to moderate yellow. Localized depressions, holding standing water, appeared moderate bluish-green to strong bluish-green, uniform and smooth. Areas of bare moist soil and dead soybean plants were moderate olive green, uniform and smooth. Cooper and Smith (1966) stated that when less than

Table 2. Features on photographs of rice fields, soybean fields and permanent pastures indicating potential *Psorophora columbiae* oviposition habitats within the riceland agroecosystem.

Field	Features
Rice	Levees Areas with standing water Dark areas of soil Ditches Tire tracks
Soybean	Areas with standing water Dark areas of soil Dark areas with few or no soybeans during wet years Areas where soybeans are replaced by moisture tolerant weeds Fallow areas within soybean fields Ditches Tire tracks
Permanent pasture	Areas with standing water Dark areas of soil Ditches Tire tracks Muddy cattle paths

25% of the ground was occupied by vegetation, the color, as seen from the air, was mostly determined by the soil. Photointerpretation and ground verification of the appearance of areas of dying and dead soybeans during our study substantiate the results of Cooper and Smith (1966). The moderate strong red to strong red to dark red, uniform, rough appearance of low areas indicated by moisture-stressed soybean plants also agrees with Cooper and Smith (1966), stating that as vegetation cover exceeded about 25%, the plants themselves contributed strongly to the apparent color and texture of the area. Low areas indicated by moisture-tolerant natural vegetation replacing soybeans were mottled, rough and moderate red and dark pink on the photographs.

Low areas within permanent pastures were variable in color due to differences in the degree to which the soil was moist. Low areas indicated by extremely moist soil were dark grayish reddish-brown to black, mottled and smooth in appearance. Low areas with soil not quite as moist appeared light olive brown, uniform and smooth, or strong yellowish-brown to moderate reddish-brown to dark reddish-orange, mottled and rough, depending on the moisture of the vegetation. Ditches with moist soil appeared as strong yellowish-brown, smooth lines running through the fields.

The appearance of levees and other potential oviposition sites of *Ps. columbiae* within rice fields on aerial CIR photographs taken during the fall is summarized in Table 4. Rice field levees were serpentine, raised, smooth and moderate yellowish-pink to strong reddish-purple, and strong red to vivid red and light pink to light purplish-pink, depending on conditions of the vegetation cover. Tire tracks appeared as parallel double serpentine lines, smooth and moderate bluish-green to strong bluish-green when filled with water, and moderate reddish-purple, dark brown to black if no standing water was present but the soil was moist.

Potential oviposition habitats within fields planted to soybeans appeared variable, depending on plant vigor and soil moisture. Low areas indicated by dead soybeans due to excess moisture were moderate olive green, uniform and rough (Figs. 1B and 2B). Low areas indicated by dying soybeans appeared pale yellowish-green, uniform and rough. Low areas with soybeans stressed due to excess moisture were pale pink to light pink to moderate pink, uniform to mottled and smooth to rough in appearance. Some low areas also appeared yellowish-white, mottled and smooth to rough. Soybeans along ditches, low areas and natural vegetation also appeared strong pink to deep pink, mottled and smooth to rough.

Areas within permanent pastures were variable in appearance, due to the type of feature and moisture conditions present at the time the photographs were taken. Ditches with moist soil were linear, smooth to rough and light olive brown. Low areas with moist soil, located in plowed portions of the field were mottled, smooth and grayish-green to dark grayish-green. Low areas with moist soil in unplowed portions appeared grayish-yellow to moderate yellow, light olive brown to dark yellow with light yellow, mottled and rough. Other low areas were

Table 3. Appearance of potential oviposition sites of *Psorophora columbiae* within fields on aerial color infrared photography taken during the summer season (i.e., 21 June to 21 September of any given year).

Date of photography	Field type	Topographic location and association	Approximate color	Pattern	Texture
Aug. 21, 1980	Rice	Levees with vegetation	Moderate yellowish pink to strong reddish orange	Serpentine	Raised, rough
		Tire tracks in harvested fields	Pale yellow to dark yellow to yellowish brown	Double serpentine	Smooth
	Soybean	Ditches	Pale orange yellow to moderate orange yellow	Linear	Smooth
	Permanent pasture	Low areas indicated by moist soil	Light olive brown	Uniform	Smooth
Sept. 10, 1981	Rice	Levees with vegetation	Strong red to dark reddish orange	Serpentine	Raised, rough
		Tire tracks in harvested fields	Pale yellow to dark yellow	Double serpentine	Smooth
	Soybean	Low areas indicated by standing water	Moderate bluish green to strong bluish green	Uniform	Smooth
		Low areas indicated by bare moist soil and dead soybeans	Moderate olive green	Uniform	Smooth
		Low areas indicated by moisture stressed soybeans	Moderate red to strong red to dark red	Uniform	Rough
		Low areas indicated by moisture tolerant natural vegetation replacing soybeans	Moderate red and dark pink	Mottled	Rough
	Permanent pasture	Low areas indicated by extremely moist soil	Dark grayish reddish brown to black	Mottled	Smooth
		Ditches with moist soil	Strong yellowish brown	Linear	Smooth
		Low areas indicated by moist soil and moisture tolerant vegetation	Strong yellowish brown to moderate reddish brown to dark reddish orange	Mottled	Rough

Table 4. Appearance of potential oviposition sites of *Psorophora columbiae* within fields on aerial color infrared photography taken during the fall season (i.e., from September 21 to December 21 of any given year).

Date of photography	Field type	Topographic location and association	Approximate color	Pattern	Texture
Oct. 6, 1979	Rice	Levees with vegetation	Moderate yellowish pink to strong reddish purple	Serpentine	Raised, smooth
		Tire tracks filled with water	Moderate bluish green	Double serpentine	Smooth
		Tire tracks in harvested fields	Moderate reddish purple	Double serpentine	Smooth
	Soybean	Low area	Yellowish white	Mottled	Smooth to rough
		Plants along ditches, low areas and natural vegetation (weeds)	Strong pink to deep pink	Mottled	Smooth to rough
	Permanent pasture	Low area	Very light bluish green to strong yellow to deep yellow	Mottled	Rough
Oct. 11, 1979	Rice	Levees with vegetation	Strong reddish purple	Serpentine	Raised, smooth
	Permanent pasture	Low area	Dark purplish red to grayish purplish pink to light purplish pink	Mottled	Rough
		Ditches	Dark purplish red to dark reddish brown	Linear	Smooth
Oct. 3, 1980	Rice	Levees with vegetation	Strong red to vivid red and light pink to light purplish pink	Serpentine	Raised, smooth to rough
		Tire tracks filled with water	Light green to strong bluish green	Double serpentine	Smooth
		Tire tracks in harvested fields	Dark brown to black	Double serpentine	Smooth
	Soybean	Low areas indicated by dead soybeans due to excessive soil moisture	Moderate olive green	Uniform	Rough
		Low areas indicated by dying soybeans due to excessive soil moisture	Pale greenish yellow	Uniform	Rough
		Low areas indicated by stressed soybeans due to excessive soil moisture	Pale pink to light to moderate pink	Uniform to mottled	Smooth to rough
	Permanent pasture	Low areas indicated by moist soil (plowed)	Grayish green to dark grayish green	Mottled	Smooth
		Low areas indicated by moist soil (unplowed)	Grayish yellow to moderate yellow, light olive brown to dark yellow with light pink	Mottled	Rough
		Ditches with moist soil	Light olive brown	Linear	Smooth to rough

visible as very light bluish-green to strong yellow to deep yellow, and dark purplish-red to grayish purplish-pink to light pink, mottled and rough locations on the photographs.

On winter photographs, fields previously planted to rice or soybeans were fallow, and vegetation in permanent pastures was usually dormant, thus permitting inspection of potential oviposition habitats normally hidden by summer vegetation canopies (Table 5). In this study, low areas indicated by standing water were uniform in pattern, smooth in texture and dark bluish-green to brilliant bluish-green (Figs. 1C and 2C) and very light blue to light blue in color on the photographs (Figs. 1D and 2D). The appearance of the low areas indicated by moist soil was moderate yellow green to moderate olive green, smooth and uniform (Figs. 1C and 2C). Ditches appeared linear, smooth, very light blue to light blue, if filled with water (Figs. 1D and 2D) and black if only wet soil was present.

The difference in appearance of characters on aerial CIR photographs indicating potential *Ps. columbiae* oviposition habitats within fields during the spring is greatly influenced by the date of photography (Table 6). Soil moisture conditions within fields were easily visible on the March 21, 1980 photographs due to the absence of vegetation cover. Areas of moist soil were still evident on the June 10, 1980 photographs; however, crops were in the field at that time.

Photographs taken in early spring are quite similar in appearance to winter photographs; soil moisture conditions and topography are still highly visible. In this study, low areas indicated by standing water were uniform, smooth, strong bluish-green to very light bluish-green to moderate blue, and moderate bluish-green, depending on turbidity of the water. Low areas with moist soil appeared mottled, smooth, light yellowish-green to moderate yellowish-green in fallow fields previously in rice or soybeans, and mottled, smooth to rough and light green to light yellowish-green to very pale green to very light bluish-green within permanent pastures.

Fields were planted to rice and soybeans at the time of the second spring overflight of 1980; conditions visible within the fields, however, were still generally due to the appearance of the soil. Levees were visible as raised, smooth, serpentine lines, light yellowish-brown to moderate orange yellow if no vegetation covered the soil, and smooth to rough, strong red to vivid red, strong pink to deep pink if vegetation was present. Low areas indicated by moist soil in soybean fields appeared mottled, smooth, and moderate yellowish-green to dark yellowish-green and light olive to moderate olive to dark olive. Low areas indicated by moist soil within permanent pastures, on the other hand, were mottled to uniform, smooth to rough and light olive to moderate olive in appearance on the aerial CIR photographs.

DISCUSSION

The literature indicates that large variations exist in the color of objects on film due to a variety of variables inherent to that pictorial element. Any portion of the spectrum to which photographic materials are sensitive can be recorded, but the colorant developed by this record can be any that are available, without regard to the initial spectral region of the object (Tarkington and Sorem 1963). Large variations in color balance can be observed with film from different batches (Malan 1974). On the same roll of film, some frames may be lighter or darker due to differences in exposure (Sayn-Wittgenstein 1978). Variations in color on photographs may also be due to the effect of the camera lens (Norton 1964), aircraft altitude, solar altitude, angle between the direction of the sun's rays and the camera, and the age of the film (Fritz 1967). Plant species and vigor of the plant can also produce variation in color (Ives 1939). Perception of color is also individual to the observer (Taranik 1972). In summary, as far as our purposes are concerned, i.e., identification of field type and ovipositional habitats, the color or name of the color is unimportant. The important thing is that color is used to differentiate between images appearing on the photographs which correspond to field type or particular physical characteristics in the field.

Results of the interpretation of the photographic data described in the Results section provided the information needed to develop the photographic characters for the various types of fields that occur in a Texas riceland agroecosystem. Although each given field type may vary in its overall appearance on given aerial CIR photographs, results indicate that certain characteristic features are present which can be used to differentiate between field types. Additionally and more importantly, potential *Ps. columbiae* oviposition habitats within the fields are identifiable on aerial CIR photographs. Reference is made to various aerial CIR photographs appearing in figures in this report. It should be noted that the colors presented in the tables are descriptors obtained from the interpretation of aerial CIR photographic transparencies and do not necessarily correspond to those colors seen in the photographs after printing in the journal.

The eventual use of aerial CIR photography as a technique for riceland mosquito surveys would not only provide for a more complete assessment of mosquito breeding conditions in a given rice producing area but would also define

Table 5. Appearance of potential oviposition sites of *Psorophora columbiae* within fields on aerial color infrared photography taken during the winter season (i.e., from December 21 to March 21 of any given year).

Date of photography	Field type	Topographic location and association	Approximate color	Pattern	Texture
Jan. 23, 1981	Rice (fallow)	Low areas indicated by standing water	Dark bluish green to very dark bluish green, moderate bluish green to brilliant bluish green	Uniform	Smooth
		Low areas indicated by moist soil	Moderate yellow green to moderate olive green	Uniform	Smooth
		Tire tracks filled with water	Dark bluish green	Double serpentine	Smooth
	Soybean (fallow)	Low areas indicated by standing water	Dark bluish green to very dark bluish green, moderate bluish green to brilliant bluish green	Uniform	Smooth
		Low areas indicated by moist soil	Moderate yellow green to moderate olive green	Uniform	Smooth
		Tire tracks filled with water	Dark bluish green	Double serpentine	Smooth
	Permanent pasture	Low areas indicated by moist soil	Moderate olive green	Uniform	Smooth
		Ditch with wet soil	Black	Linear	Smooth
Feb. 2, 1981	Soybean (fallow)	Low areas indicated by standing water	Very light blue to light blue	Uniform	Smooth
		Low areas indicated by moist soil	Moderate olive green	Uniform	Smooth
		Ditch filled with water	Very light blue to light blue	Linear	Smooth

Table 6. Appearance of potential oviposition sites of *Psorophora columbiae* within fields on aerial color infrared photography taken during the spring season (i.e., from March 21 to June 21 of any given year).

Date of photography	Field type	Topographic location and association	Approximate color	Pattern	Texture
Mar. 21, 1980	Rice (fallow)	Low areas indicated by standing water	Strong bluish green to very light bluish green to moderate blue	Uniform	Smooth
		Low areas indicated by moist soil	Light yellowish green to moderate yellowish green	Mottled	Smooth
		Ditch filled with water	Strong bluish green	Linear	Smooth
	Soybean (fallow)	Low areas indicated by standing water	Strong bluish green to very light bluish green to moderate blue		
		Low areas indicated by moist soil	Light yellowish green to moderate yellowish green	Mottled	Smooth
		Ditch filled with water	Strong bluish green	Linear	Smooth
	Permanent pasture	Low areas indicated by standing water	Moderate bluish green	Uniform	Smooth
		Low areas indicated by moist soil	Light green to light yellowish green to very pale green to very light bluish green	Mottled	Smooth to rough
		Ditch filled with water	Moderate bluish green	Linear	Smooth
		Tire tracks filled with water	Moderate bluish green	Double serpentine	Smooth
Jun. 10, 1980	Rice	Levees with bare soil	Light yellowish brown to moderate orange yellow	Serpentine	Raised, smooth
		Levees with vegetation	Strong red to vivid red, strong pink to deep pink	Serpentine	Raised, smooth to rough
	Soybean	Low areas indicated by moist soil	Moderate yellowish green to dark yellowish green and light olive to moderate olive to dark olive	Mottled	Smooth
	Permanent pasture	Low areas indicated by moist soil	Light olive to moderate olive	Mottled to uniform	Smooth to rough

areas that should be targeted for mosquito control efforts. The better definition of such targets would allow for a more efficient use of mosquito control manpower and materials and would reduce the overall impact that mosquito control efforts have on the environment since these efforts would be limited to only those areas actually requiring them.

Photointerpretation of aerial CIR photographs obtained from the eight photographic missions suggests this remote sensing technique should be of value to mosquito control practitioners by increasing the accuracy and efficiency of surveillance of potential *Ps. columbiae* oviposition habitats. In addition to providing land-use patterns and crop distribution, surveys with aerial CIR photography are capable of locating potential oviposition sites previously unknown to mosquito control personnel because the habitat was hidden from view at ground level.

Knowledge acquired during this study suggests the following conclusions on the uses of aerial CIR photography as a survey technique. Aerial CIR photography may be used to survey and catalog fields as to use or crop: rice, a known source of *Ps. columbiae*; soybeans, a potentially important source under certain weather conditions; and permanent pastures, perhaps a relatively unimportant source of *Ps. columbiae*. Aerial CIR photography may be used to locate specific topographical features (potential oviposition habitats) such as levees, tire tracks, localized depressions and ditches within fields.

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